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EMPIRICAL DETERMINATION OF THE HEAT CAPACITY, TIME CONSTANT, AND SENSITIVITY OF EARTH'S CLIMATE SYSTEM

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ABSTRACT

Atmospheric concentrations of CO_2 will continue to increase throughout this century. How much will global temperature increase? This depends both on future emissions and on climate system response to resultant forcings. The key measure of climate response to forcings is the equilibrium sensitivity, the increase in global mean surface temperature resulting from a sustained imposed forcing. This quantity, estimates of which go back to Arrhenius, is not well known; present estimates range over a factor of 3 or more. This uncertainty translates directly into uncertainty in the amount of incremental atmospheric CO_2 that would result in a given increase in global mean surface temperature and hence into uncertainty in the amount of fossil fuel carbon that can be combusted consonant with a given effect on climate. Climate models are essential to providing detailed answers to climate effects of specific policy options, but at present these models remain highly uncertain even in their global mean sensitivities. Here I introduce an empirical approach to determining climate sensitivity based on energy balance considerations as the quotient of the time constant of climate response to a perturbation upon the effective heat capacity of the planet that is coupled to climate change on the multidecadal scale. Both of these quantities are evaluated from observational data. The heat capacity of the global ocean, obtained from regression of ocean heat content from 1960 to the present vs. global mean surface temperature (GMST) is 14 ± 6 W yr m^{-2} K^{-1}, equivalent to 110 m of ocean water; other sinks raise the effective planetary heat capacity to 17 ± 7 W yr m^{-2} K^{-1} (all uncertainties are 1-sigma estimates). The time constant of the climate system determined from autocorrelation of GMST over 1880-2004 is 5 ± 1 yr, although that result has been questioned. The resultant equilibrium climate sensitivity, 0.30 ± 0.14 K/(W m^{-2}), corresponds to an equilibrium temperature increase for doubled CO_2 of 1.1 ± 0.5 K, low compared to other current estimates. The short time constant implies that GMST is in near equilibrium with applied forcings with little residual heating "in the pipeline" due to incremental greenhouse gases already in the atmosphere.
